GIS-Based Land Suitability Assessment for Corn and Garlic Production in the Quiaoit River Watershed, Ilocos Norte, Philippines

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ABSTRACT

This study assessed the land suitability for corn (*Zea mays* L.) and garlic (*Allium sativum* L.) production in the Quiaoit River Watershed (QRW), Ilocos Norte, Philippines, using a Geographic Information System (GIS)–based multi-criteria approach. By integrating soil properties, topography, climate, and water availability, the analysis aimed to identify areas where each crop can be sustainably grown and to highlight key environmental constraints affecting productivity. Soil parameters, including pH, organic matter, nutrient content, texture, depth, and drainage, were combined with slope, temperature, rainfall, and aquifer capacity data, following standards set by the FAO and the Bureau of Soils and Water Management. Factor weights were assigned using the Analytical Hierarchy Process (AHP) to reflect the relative importance of each criterion for corn and garlic production. The results indicate that much of the watershed is moderately to highly suitable for corn, particularly in gently sloping areas with deep clay loam soils, favorable pH, and reliable groundwater supply. In contrast, garlic suitability is generally moderate, constrained mainly by low soil organic matter and climatic conditions that can limit optimal bulb development. Spatial analysis showed that approximately 419.5 ha are highly suitable and 7,640 ha are moderately suitable for corn, while 8,420 ha are moderately suitable and 441 ha are marginally suitable for garlic. These patterns suggest that while the QRW has strong potential for corn production, garlic cultivation requires more careful management to address soil fertility and water-related limitations. The study highlights the value of GIS-based suitability mapping as a practical decision-support tool for agriculture. Targeted improvements in soil organic matter, efficient irrigation practices, and appropriate slope management can help overcome identified constraints and enhance crop productivity. The generated suitability maps provide a clear basis for crop zoning, land-use planning, and sustainable watershed management, supporting climate-resilient agricultural development in Ilocos Norte.

Keywords: *Corn, Garlic, GIS, land suitability, sustainable agriculture*

Introduction

Agriculture remains a cornerstone of rural livelihoods and food security in the Philippines, yet its sustainability is increasingly challenged by rapid land conversion, declining soil fertility, and growing climate variability (Salvacion et al., 2023; Department of Agriculture [DA], 2023). These pressures make it difficult for farmers and planners to determine where specific crops can be productively and sustainably grown. Land suitability assessment addresses this challenge by providing a systematic, science-based framework for matching crops with the biophysical conditions of the land, taking into account soil properties, climate, topography, and water resources (Food and Agriculture Organization [FAO], 2020; Malczewski & Rinner, 2022). When integrated with Geographic Information Systems (GIS) and multi-criteria decision analysis, land suitability assessment enables spatially explicit evaluation of agricultural potential, offering practical guidance for land-use planning and policy formulation (Amongo et al., 2023; Cogay et al., 2020).

The Quiaoit River Watershed (QRW) in Ilocos Norte exemplifies the need for such an approach. The watershed supports the agricultural systems of Batac, Currimao, and Paoay, where farming remains central to local economies. In Paoay, corn production underpins the well-known *chichacorn* industry, making the continued availability of suitable land for corn a matter of both economic and cultural importance. At the same time, garlic (*Allium sativum* L.), a high-value crop traditionally associated with Ilocos agriculture, has experienced declining productivity due to soil nutrient depletion and increasing climatic stress (Bucao et al., 2023).

Previous land suitability studies in the watershed (e.g., Utrera et al., 2017) provided valuable baseline information but were constrained by coarse spatial resolution, limited soil fertility indicators, and earlier GIS methodologies that did not fully capture topographic variability or water availability. As a result, earlier models offered generalized suitability patterns but lacked the spatial detail needed for targeted crop zoning and climate-responsive planning. Recent advances in geospatial data, including LiDAR-derived elevation models and improved soil and hydrologic datasets, now allow for a more refined and reliable assessment of land suitability.

Building on these advances, this study applied updated spatial datasets, LiDAR-based topographic analysis, and the Analytical Hierarchy Process (AHP) within a GIS framework to reassess land suitability for corn and garlic in the QRW. The overarching objective is to generate a more precise, evidence-based understanding of where these crops can be sustainably grown and what constraints limit their productivity. Specifically, the study aimed to: (1) characterize the physical and chemical properties of the major soils in the Quiaoit River Watershed; (2) evaluate the suitability of key environmental factors influencing crop production; and (3) identify and map areas suitable for corn and garlic cultivation. By addressing the limitations of earlier assessments, the study seeks to support climate-resilient, resource-efficient, and economically viable agricultural development in the Quiaoit River Watershed.

Methods

Locale of the Study

The study was conducted in the Quiaoit River Watershed (QRW), located in the province of Ilocos Norte, Northern Philippines (Figure 1). The watershed covers an approximate area of 190.18 km², encompassing the City of Batac and the municipalities of Paoay and Currimao. Paoay is known for its distinctive agro-based product, *chichacorn*, a local delicacy derived from glutinous corn, which underscores the cultural and economic importance of corn production in the area.

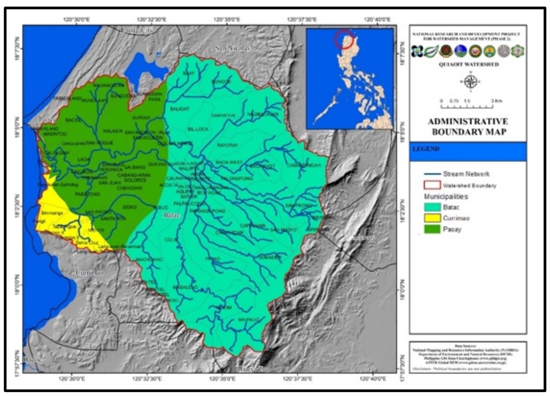

Figure 1. Administrative boundary map of the Quiaoit River Watershed.

QRW lies between latitudes 17°07′N and longitudes 120°28′–120°32′E, about 11 km east of the South China Sea. The area exhibits Type I climate characterized by two distinct seasons: a dry season from November to April and a wet season from May to October. The mean annual rainfall is approximately 2,100–2,500 mm, and the mean monthly temperature ranges between 25°C and 27°C. Elevations vary from near sea level along the western coastal zone to about 520 m above sea level in the uplands. The watershed's geology consists mainly of Miocene–Pliocene sedimentary formations, limestone in lower zones, and recent alluvial deposits along the river valley.

Agriculture is the predominant land use in the QRW, with rice, corn, garlic, and tobacco as major crops. Soils are predominantly clay loam to loam, derived from alluvial and calcareous limestone parent materials, with moderate fertility and good water-holding capacity.

Data Collection

Soil sampling points were identified across major soil series within the watershed using stratified random sampling based on landform and slope (Figure 2). Composite soil samples were collected at a depth of 0–30 cm, and analyzed at the Ilocos Norte Provincial Agriculture Office for the following parameters:

- Soil pH (1:1 soil–water ratio),
- Organic matter (OM) using Walkley–Black method,
- Available phosphorus (P) using Olsen's method,
- Exchangeable potassium (K) via ammonium acetate extraction

Texture was based on the Soil Type Map requested from the Bureau of Soils and Water Management. Soil depth and drainage class were assessed in situ following Bureau of Soils and Water Management (BSWM) protocols.

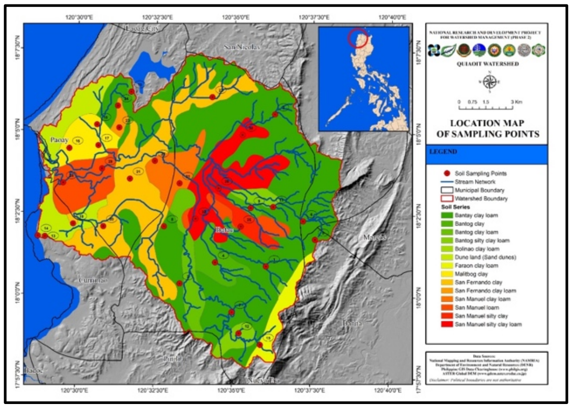

Figure 2. Location of soil sampling points at the Quiaoit River Watershed.

Climatic, Topographic, and Hydrologic Data

Climatic data (temperature, rainfall, relative humidity) were obtained from PAGASA synoptic and agro-meteorological stations in Laoag and Batac, respectively. Long-term averages (1991–2020) were used to minimize interannual variability.

Topographic data, including Digital Elevation Model (DEM) and slope, were derived from LiDAR datasets provided by the University of the Philippines Disaster Risk and Exposure Assessment for Mitigation (UP DREAM–LiDAR) program. Hydrologic data, particularly aquifer specific capacity and groundwater availability, were sourced from previous aquifer characterization studies and verified through field observations.

GIS Data Processing

All spatial datasets were processed in ArcGIS 4.0. The workflow (Figure 3) involved the following steps:

1. Interpolation: Point-based soil attributes (pH, OM, P, K) were spatially interpolated using Inverse Distance Weighting (IDW) to generate continuous raster surfaces.
2. Reclassification: Each raster dataset was reclassified into four suitability classes—Highly Suitable (S1), Moderately Suitable (S2), Marginally Suitable (S3), and Unsuitable (N)—based on threshold values adapted from FAO (2020) and BSWM (2017) standards.
3. Masking and Clipping: Reclassified layers were clipped to the QRW boundary and masked using land use data (2019 LiDAR-derived land cover) to focus only on agricultural lands.
4. Normalization: Raster values were normalized (0–1 scale) to ensure comparability across datasets prior to overlay analysis.

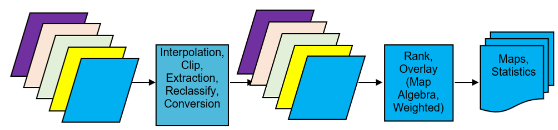

Figure 3. Geoprocessing Model Used in the Study

Criteria and Factors

Four main factors were considered in the suitability assessment:

1. Climate (temperature, rainfall, relative humidity),
2. Soil properties (texture, pH, OM, P, K, depth, drainage),
3. Topography (slope), and
4. Water availability (aquifer capacity).

Each factor was evaluated for its influence on corn and garlic growth requirements based on agronomic guidelines and local production data.

Analytical Hierarchy Process (AHP)

The Analytical Hierarchy Process (AHP) was used to assign relative importance to the factors influencing land suitability for corn and garlic production in the Quiaoit River Watershed. This method was chosen because it allows expert

knowledge to be incorporated in a structured and transparent way, while also checking that the assigned priorities are logically consistent.

Expert input was obtained from a group of specialists with practical and academic experience in agronomy, soil science, water resources, and GIS-based land evaluation. The panel included selected faculty members and practitioners from Mariano Marcos State University and the Provincial Agriculture Office, who are familiar with crop production and land management conditions in Ilocos Norte. Experts were selected based on their relevant educational background, at least five years of professional experience, and direct knowledge of local agro-environmental settings.

Each expert was asked to compare the importance of the main criteria—climate, soil properties, topography, and water availability—pair by pair for corn and garlic, using Saaty's 9-point comparison scale. Conducting the evaluation separately for each crop allowed the weighting process to reflect their different growth requirements and sensitivities to environmental conditions.

Individual judgments were combined using the geometric mean to produce a single consensus matrix for corn and another for garlic. From these matrices, the normalized principal eigenvectors were calculated to obtain the final weights for each criterion. For corn, greater importance was given to soil properties and water availability, reflecting the crop's dependence on soil fertility and supplemental irrigation, while climate received a relatively lower weight due to corn's wider climatic tolerance. In contrast, climate emerged as the most influential factor for garlic, followed by soil properties, consistent with its sensitivity to temperature and humidity during bulb development.

To verify the reliability of the expert judgments, the Consistency Index (CI) and Consistency Ratio (CR) were computed for each matrix. A CR value of 0.10 or lower was considered acceptable, following standard AHP guidelines. All comparison matrices met this requirement, indicating that the evaluations were internally consistent. The final criterion weights and their corresponding CR values are presented in Table 1. The criteria showing the different factors considered for the suitability of garlic and corn production are shown in Table 2.

Table 1. AHP-derived criterion weights and consistency ratios (CR) for corn and garlic suitability analysis.

Criterion	Weight		Rank	
	Corn	Garlic	Corn	Garlic
Climate	0.25	0.55	2	1
Soil Properties	0.25	0.15	2	2
Topography (Slope)	0.25	0.15	2	3
Water Availability	0.25	0.15	2	3
Consistency Ratio (CR)	0.08	0.08	--	--

Table 2. Criteria for the suitability of garlic and corn production.

Factor	Value/Class		Suitability Rating
	Garlic	Corn	
Climatic (weight)	(55%)	(25%)	
Relative Humidity/ Rainfall (mm)	≥ 88	<500	Unsuitable
	85 – 87	500 - 750	Marginally Suitable
	82 – 84	750 - 900	Moderately Suitable
	≤ 81	>900	Highly Suitable
Mean Monthly Temperature (°C)	>32	>40 / <10	Unsuitable
	27 - 32	39 - 40 / 10 - 50	Marginally Suitable
	22-26	33 – 38 / 15 - 20	Moderately Suitable
	<22	21 - 32	Highly Suitable
Soil Property (weight)	15%	25%	
Texture	Heavy clay or sandy	Heavy clay or sandy	Unsuitable
	SiC or C	C or LS	Marginally Suitable
	SC or LS or SL or SiCL	SiC or SL or SiCL	Moderately Suitable
	L or SiL or SCL or CL	L or SiL or SCL or CL	Highly Suitable
Depth (cm)	< 15	< 25	Unsuitable
	16 – 35	25 - 50	Marginally Suitable
	36 – 50	51 - 75	Moderately Suitable
	> 50	> 75	Highly Suitable
Drainage	Very poor or very excessive	Very poor or very excessive	Unsuitable
	Poor – excessive	Poorly/ Excessively	Marginally Suitable
	Fair	Mod. to imperfectly	Moderately Suitable
	Good	Well Drained	Highly Suitable
pH	<4.5 or >8.5	<4.5 / >9.0	Unsuitable
	4.5 – 5.5 or 8.0 – 8.5	4.5 – 5.0 or 8.6 – 9.0	Marginally Suitable
	5.6 – 6.5 or 7.6 – 8.1	5.1 – 5.4 or 7.6 – 8.5	Moderately Suitable
	6.6 – 7.5	5.5 – 7.5	Highly Suitable
OM (kg)	< 2.0	< 2.0	Unsuitable
	2.1 – 3.5	2.1 – 3.5	Marginally Suitable

Factor	Value/Class		Suitability Rating
	Garlic	Corn	
Exchangeable K (kg)	3.6 – 4.5	3.6 – 4.5	Moderately Suitable
	> 4.50	> 4.50	Highly Suitable
	<100	<100	Unsuitable
	100-175	100-175	Marginally Suitable
	175-250	175-250	Moderately Suitable
	>250	>250	Highly Suitable
Available P (kg)	<11	<11	Unsuitable
	11.5-20.0	11.5-20.0	Marginally Suitable
	20.0 -30.0	20.0 -30.0	Moderately Suitable
	>30.0	>30.0	Highly Suitable
Supplemental (weight)	(15%)	(25%)	
Quantity of groundwater (m^3/m-day)	< 200	< 200	Unsuitable
	200 – 500	200 - 500	Marginally Suitable
	501 - 1000	501 - 1000	Moderately Suitable
	>1000	>1000	Highly Suitable
Topographic Factors (weight)	(15%)	(25%)	
Slope (%)	0 – 3	0 – 3	Highly Suitable
	3 – 8	3 – 8	Moderately Suitable
	8 – 18	8 – 18	Marginally Suitable
	>18	>18	Unsuitable

The AHP-derived weights were then integrated into the GIS analysis using a Weighted Linear Combination approach. Each standardized raster layer contributed to the overall suitability index in proportion to its assigned weight for corn and garlic. By combining expert knowledge, consistency testing, and spatial analysis, the AHP framework strengthened the transparency, reliability, and crop-specific relevance of the land suitability assessment.

Weighted Overlay Analysis

The Weighted Linear Combination (WLC) technique was applied to integrate all reclassified and normalized raster layers using the equation:

$$S = \sum_{i=1}^{n} w_i \times r_i$$

where S is the composite suitability index, w_i is the AHP-derived weight, and r_i is the standardized raster value for criterion *i*.

The resulting composite raster was reclassified into four suitability classes (S1–N) and converted into vector polygons for area statistics. Final suitability maps for corn and garlic were generated and overlaid with administrative boundaries to identify priority areas in Paoay, Batac, and Currimao.

Validation and Analysis

Ground validation was conducted through field visits and informal farmer interviews at representative locations to verify crop occurrence and observable physical conditions relative to the modeled land suitability classes. Validation focused on the presence or absence of corn and garlic and the visual assessment of key physical suitability factors, including physical soil properties, topography, land use/land cover, and water availability, rather than on crop yield performance. farmers' preferences and economic capacity. In locations where the crop was absent, suitability was evaluated using the criteria based on visual inspection of the physical factors.

Subsequently, the initially classified suitable based on crop occurrence were further refined into highly and moderately suitable classes using the criteria on physical factors.

Areas where the target crop was present were initially considered suitable, acknowledging that crop occurrence reflects both biophysical suitability and

Results

Soil Physical Properties

Most of the soils (9,977.50 ha) within the watershed have clay loam texture (Table 2). This suggests that these are favorable or highly suitable for corn and garlic production (Figure 4).

Soil depth also affects crop production. The optimum soil depth for crop production is 50 cm. As shown in Figure 5, most of the soils in the region are deep (>50 cm) and thus highly suitable for corn and garlic production. Areas rated as highly suitable are characterized by a relatively deep soil with a depth deeper than 50 cm and 75 cm for garlic and corn, respectively, while areas rated as unsuitable are those that are shallow with a depth ranging from 0-15 cm and 0-25 cm for garlic and corn, respectively. Under these conditions, root penetration is obstructed by the presence of stones, boulders, or the parent materials and thus affects the absorption of nutrients by the plants. Also, shallow soil limits the availability of nutrients due to its limited capacity to store and hold nutrients.

Generally, however, heavy clay soils have poor to very poor drainage due to their smaller soil particles. On the contrary, very light soils have excessive to very excessive drainage due to their very coarse particles. These conditions both affect crop production as they will affect aeration, moisture retention, and irrigation frequency, which are crucial to the growth and development of the plant. However, most of the soil has a favorable drainage for corn and garlic production (Figure 6). Among the deep soils are Bantay, Bantog, and San Manuel.

Table 2. Physical characteristics of the major soils in the QRW.

Soil Description	Area (ha)	Effective Depth (cm)	Drainage	Texture rating	Depth rating	Drainage rating
Bantay clay loam	8068.70	94.00	Fair	4	4	3
Bantog clay	717.47	90.00	Very poor	2	4	1
Bantog clay loam	651.46	90.00	Poor	4	4	1
Bantog silty clay loam	486.14	90.00	Very Poor	3	4	1

Bolinao clay loam	9.56	45.00	Good	4	2	2
Dune land (Sand dunes)	1208.04	0.00	Very Excessive	1	4	1
Faraon clay loam	479.58	40.00	Good	4	2	3
Malitbog clay	669.08	88.00	Very poor	2	4	3
San Fernando clay	2955.17	88.00	Poor	2	4	2
San Fernando clay loam	117.38	88.00	Good	4	4	4
San Manuel clay loam	650.82	100.00	Good	4	4	4
San Manuel loam	1195.32	100.00	Good	4	4	4
San Manuel silty clay	323.31	100.00	Good	3	4	4
San Manuel silty CL	1486.01	100.00	Good	3	4	4

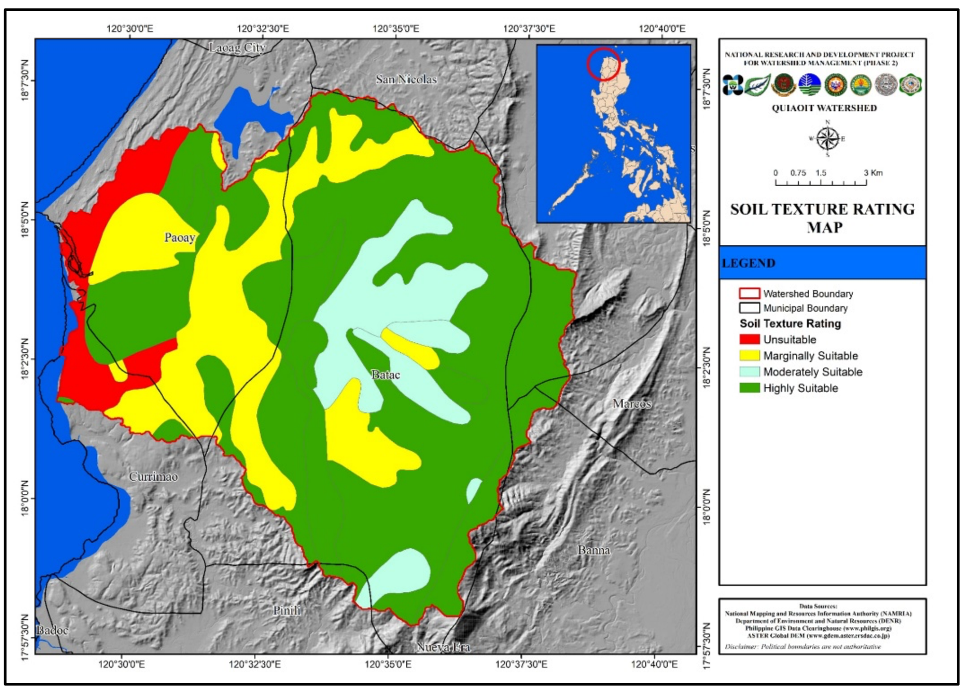

Figure 4. Soil texture rating map for crop production in the QRW.

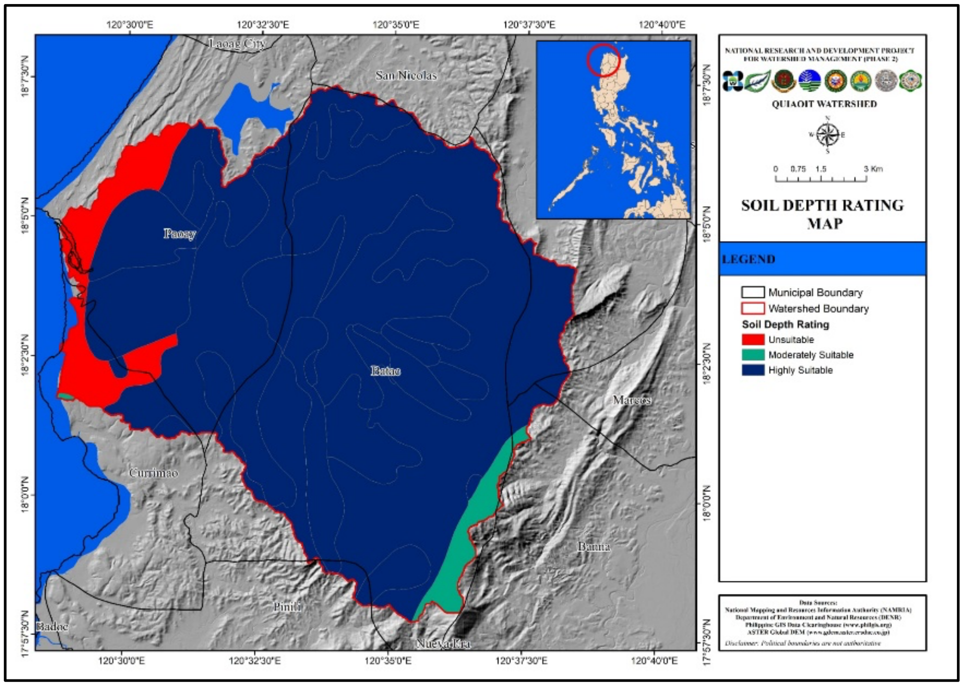

Figure 5. Soil depth rating map for crop production in the QRW.

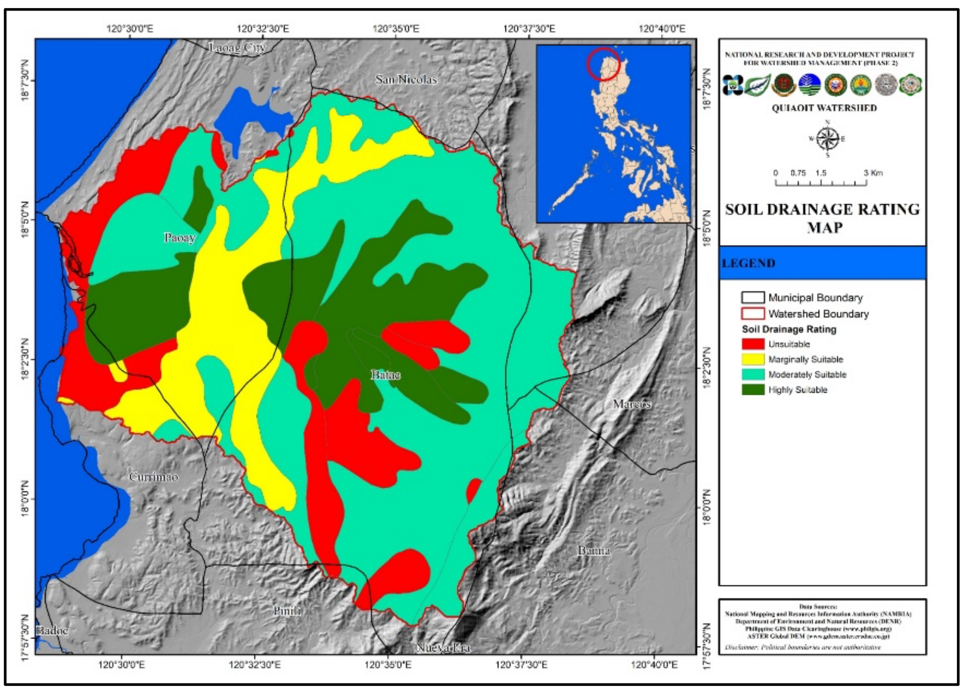

Figure 6. Soil drainage rating map for crop production in the QRW.

Soil Chemical Characteristics

Soil pH is a measure of the acidity and alkalinity in soils. The optimal pH range for most plants is between 5.5 and 7.0; however, many plants have adapted to thrive at pH values outside this range. According to Philippine recommendations for soil fertility management, pH ranging from 5.5–8.5 is adequate or favorable for crop production. Because pH levels control many chemical processes that take place in the soil – specifically, plant nutrient availability – it is vital to maintain proper levels for plants to reach their full yield potential. Potential hydrogen (pH) of soil within the QRW ranges from 4.30–7.80 (Table 3). The majority of the soils are alkaline and, based on the criteria, are classified as adequate or favorable for corn and garlic production (Figure 7).

The organic matter (OM) content of most of the soils in the watershed ranges from 0.62% to 4.07%. Based on the obtained OM content, the majority of the soils (14,951.25 ha) within the QRW are classified as unsuitable for crop production (Figure 8). Portions of the soil are classified as marginally suitable (3,950 ha) while the rest are classified as moderately suitable (113.25 ha) for crop production. This indicates that the current condition of some soils or farms in the QRW is already degraded. This might be due to the increased mineralization rates brought about by heavy application of synthetic fertilizers and pesticides and tillage practices or removal of crop residues. OM affects both the chemical and physical properties of the soil and its overall health, which includes soil structure; moisture holding capacity; diversity and activity of soil organisms, both those that are beneficial and harmful to crop production; and nutrient availability (Bot and Benites, 2005). However, organic matter content could be increased by the application of organic fertilizers.

Phosphorus is a crucial component for converting solar energy into food, fiber, and other plant products. It plays a vital role in the metabolism of sugars, energy storage and transfer, cell growth, and the transfer of genetic information (Wyant et al, 2013). The results of the analysis on the available phosphorus content range from 0.82 ppm to 100.62 ppm, with 40% of the area classified as moderately suitable. Based on the general guidelines for fertility rating soils (PCAARRD, 2006), the majority of the obtained P content falls under unsuitable (6,845.0 ha) and marginally suitable (9245.3 ha) rating (Figure 9), and only a small portion was classified as moderately suitable (1,712.3 ha) and highly suitable (1,212.0 ha). To increase the amount of phosphorus, phosphate fertilizer has to be applied. However, the soil pH must be checked first: extreme acidity and basicity render phosphorus unavailable to plants. A pH range of 6-7 is desirable. In cases where soil acidity is a problem, the pH can be raised to optimum by application of lime to make the soil responsive to phosphate fertilization.

For the amount of exchangeable potassium, values range from 80.29 ppm to 1174.81 ppm. Based on the general guidelines for fertility rating soils (PCAARRD, 2006), the majority of the obtained K content falls under highly suitable (14,156.8 ha) and moderately suitable rating (4,146.0 ha) (Figure 10). In case of deficiency, application of potassium should be made. Soils with moderate to good internal drainage may usually respond to potassium application. Exchangeable potassium (K) content was high in most soil series (>250 ppm), classifying nearly 75% of the area as highly suitable (S1) for both crops (Figure 10).

Table 3. Soil chemical properties in the Quiaoit River Watershed.

Code	Latitude	Longitude	Texture	pH	%OM	%N	ppmP	ppmK
1	18.015158	120.601093	light	7.30	1.34	0.067	25.24	565.91
2	18.005941	120.555303	heavy	4.30	2.26	0.113	100.62	159.37

3	18.092725	120.604967	heavy	6.50	2.13	0.107	13.45	490.34
4	18.016911	120.57401	heavy	7.40	1.30	0.065	7.61	263.18
5	18.02904	120.626986	heavy	7.60	1.27	0.064	47.96	198.92
6	18.038393	120.620534	heavy	7.40	1.07	0.054	0.82	376.88
7	17.991677	120.583127	heavy	6.80	1.14	0.057	3.26	292.84
8	18.035006	120.546599	heavy	7.60	2.24	0.112	15.15	243.41
9	18.04488	120.592633	heavy	7.30	1.31	0.066	7.61	1175.14
10	18.103383	120.528318	heavy	7.30	1.28	0.064	3.68	396.66
11	18.045545	120.604555	heavy	7.50	1.71	0.086	11.22	421.37
12	17.980943	120.587006	heavy	7.00	0.87	0.044	17.91	100.05
13	18.029324	120.483321	heavy	5.50	2.82	0.141	13.24	273.07
14	18.02955	120.479565	heavy	5.40	1.87	0.094	30.44	114.88
15	17.975175	120.598406	heavy	7.20	1.24	0.062	15.36	149.48
16	18.074335	120.495772	heavy	5.50	2.11	0.106	13.56	476.93
17	18.075934	120.511197	heavy	5.60	0.62	0.031	7.50	273.07
18	18.086576	120.510373	heavy	7.50	2.50	0.125	7.61	164.31
19	18.035879	120.498254	heavy	6.80	2.39	0.120	15.89	436.20
20	18.034686	120.514309	heavy	7. 40	4.07	0.204	8.89	218.69
21	18.059081	120.528181	heavy	7.60	2.40	0.120	14.62	164.31
22	18.101144	120.571531	heavy	6.80	1.34	0.067	8.78	312.62
23	18.085098	120.522184	heavy	7.60	2.04	0.102	26.72	312.62
24	18.096249	120.52131	heavy	7.30	1.72	0.086	9.10	258.24
25	18.035354	120.587413	heavy	7.30	2.17	0.109	7.08	243.41
26	18.054683	120.575343	heavy	7.80	1.53	0.077	25.98	268.13
27	18.068306	120.541359	heavy	6.70	1.47	0.074	2.62	307.67
28	18.056715	120.492674	heavy	7.60	0.89	0.045	9.42	367.00
29	18.064081	120.513252	medium	7.70	1.56	0.078	3.89	154.43
30	18.08204	120.587829	medium	7.60	2.28	0.114	2.62	297.79
31	18.057008	120.554635	medium	7.80	1.15	0.058	9.20	367.00
32	18.039068	120.563307	medium	7.80	1.68	0.084	17.38	80.27

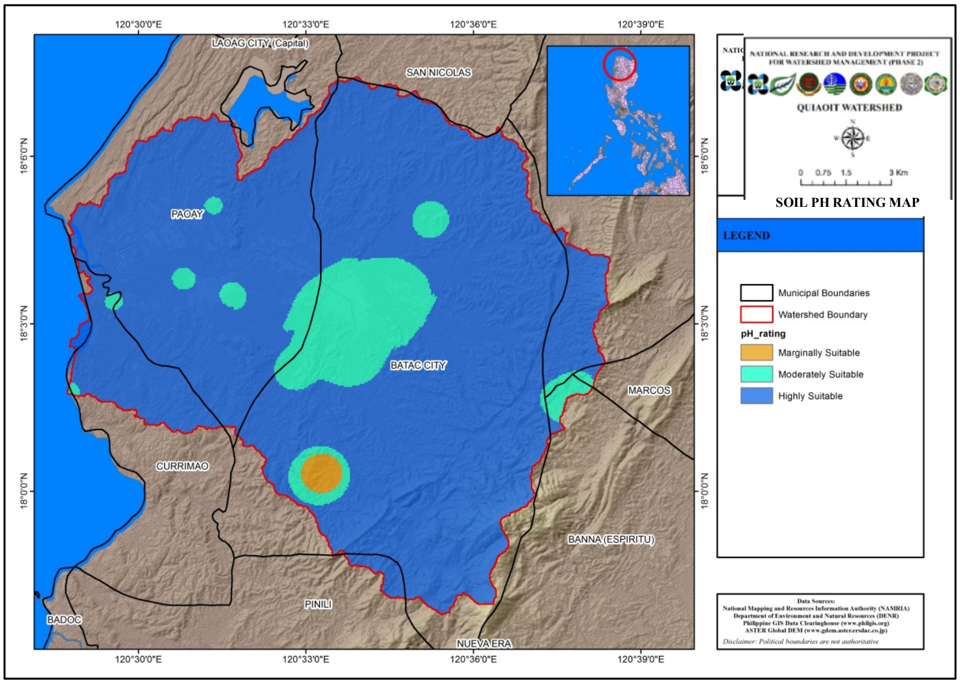

Figure 7. Soil pH rating map in the QRW.

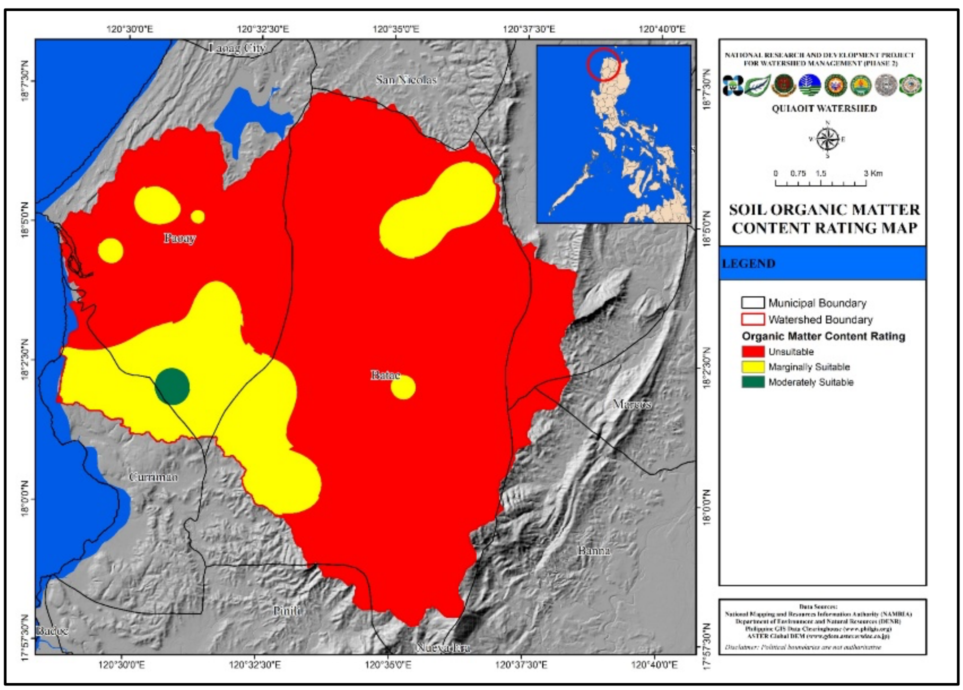

Figure 8. Soil organic matter rating map in the QRW.

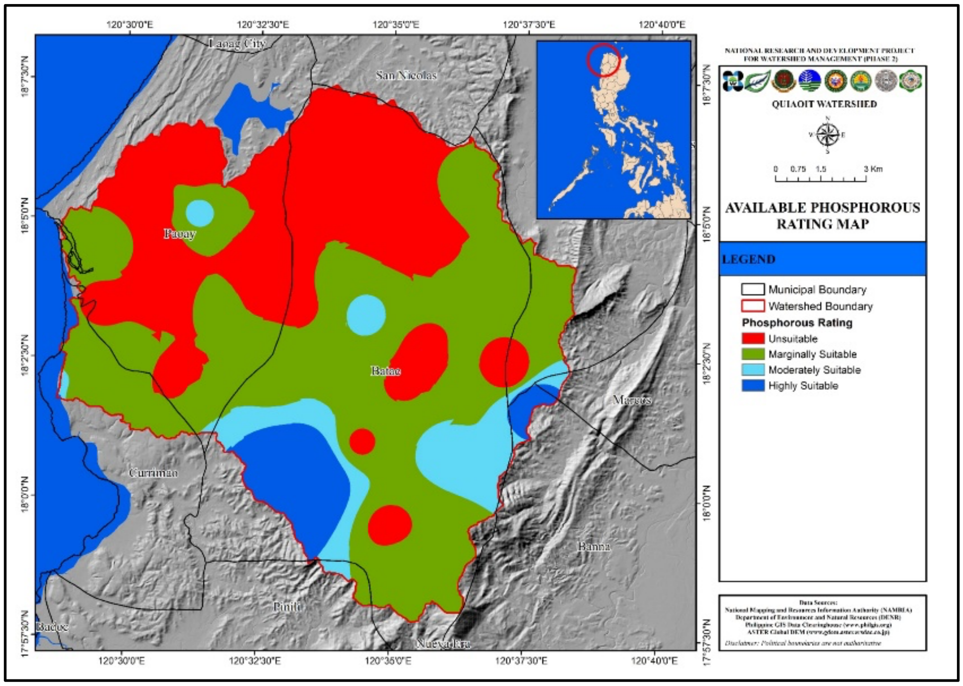

Figure 9. Soil available phosphorus rating map for crop production in the QRW.

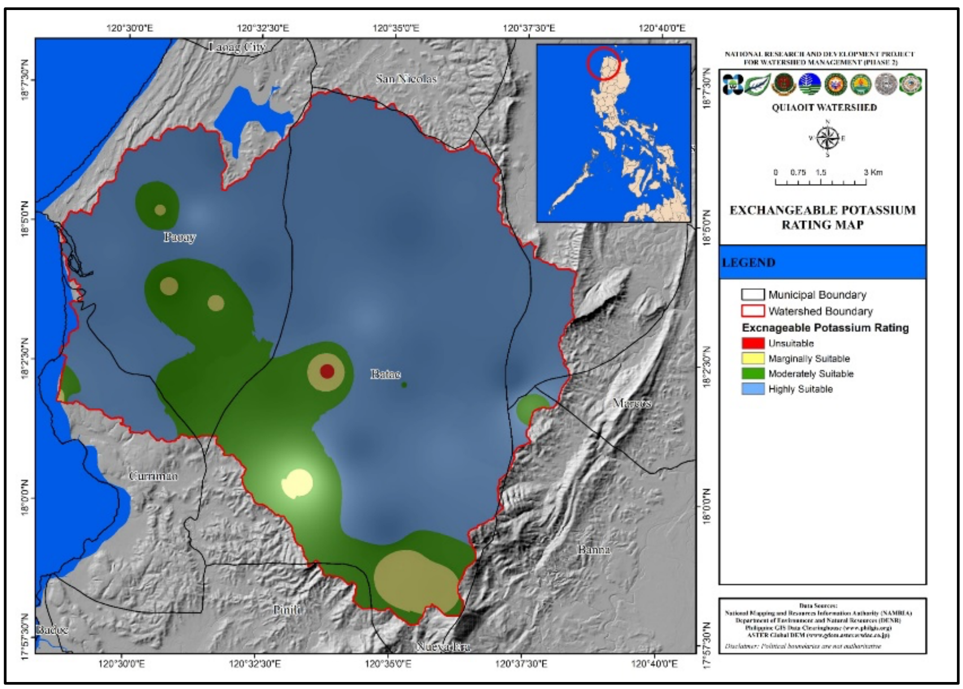

Figure 10. Exchangeable potassium rating map for crop production in the QRW.

Suitability Factors

Climatic Factor

The climatic factors used in the land suitability assessment highlight the contrasting climate sensitivities of corn and garlic in the Quiaoit River Watershed. Corn is relatively climate-resilient and can perform well across a broad range of temperatures and rainfall conditions. This adaptability explains why climatic factors were assigned moderate weight in the evaluation. Under the watershed's Type I climate, mean monthly temperatures of about 26 °C and an average annual rainfall of approximately 2,100 mm create favorable growing conditions for corn. Seasonal rainfall not only supports crop growth during the wet months but also replenishes groundwater and surface water sources that help sustain production during short dry periods.

Garlic, in contrast, is more sensitive to climatic conditions, particularly temperature and relative humidity during bulb development. Consequently, climate factors were given greater weight in the garlic suitability analysis. Although relative humidity in the QRW is generally favorable, prevailing temperatures are only marginally suitable for optimal bulb formation, as warmer conditions can induce heat stress and reduce bulb size. This sensitivity explains why areas that are highly suitable for corn are often rated only moderately suitable for garlic. Overall, the differing climate factor weights reflect corn's greater tolerance to local climatic variability and garlic's reliance on more narrowly defined temperature and humidity conditions.

Soil Factor

The combined soil property factor map shows that most of the soils in the QRW are moderately to highly suitable for corn (Figure 11) and garlic (Figure 12). This could be mainly attributed to its high potassium content, moderate phosphorus content, favorable pH, moderate to fine texture, medium soil depth, and favorable drainage. It was noted that some of the physical and chemical properties were not favorable or low in amount, e.g., organic matter content, but this could be improved by proper practice and soil management, e.g., application of organic fertilizers, to make it more favorable for corn and garlic production.

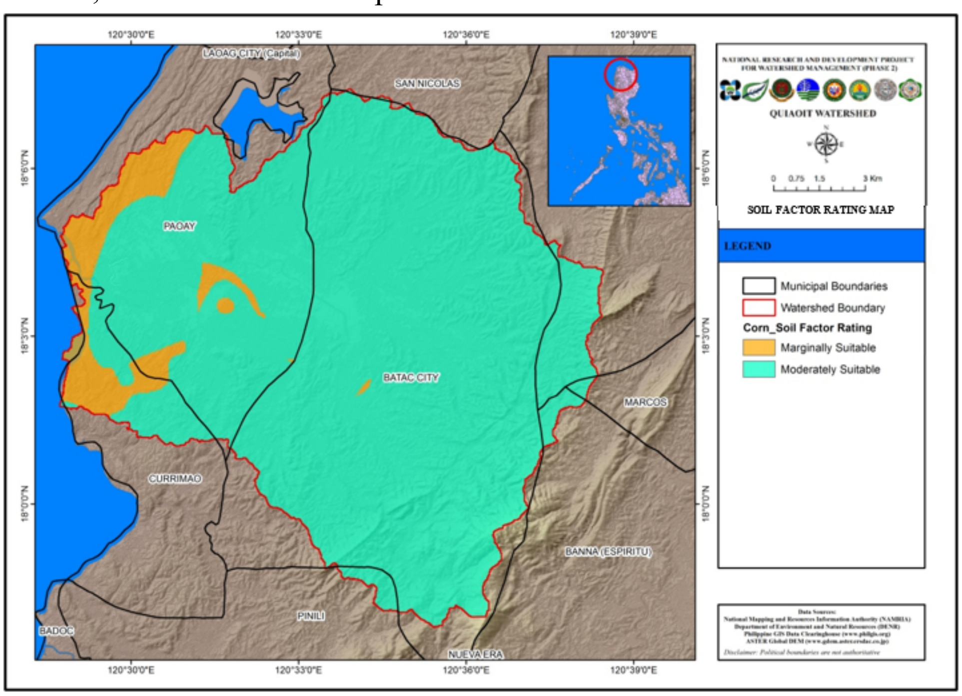

Figure 11. Soil factor rating map for corn production in the QRW.

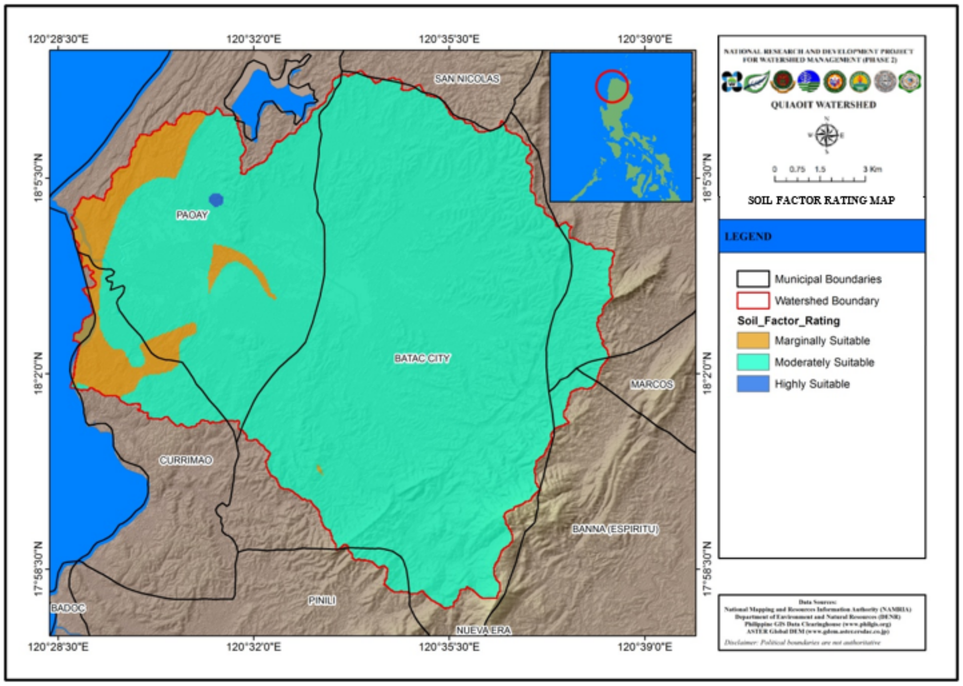

Figure 12. Soil factor rating map for garlic production in the QRW.

Topographic Factor

Topography also affects crop production, particularly slope. The slope map of QRW extracted using LiDAR data was used. For corn and garlic production, areas with slope >18% are classified as unsuitable, while areas with slope 8 - 18% were classified as marginally suitable for crop production. Gently sloping to undulating (3-8%) was rated as moderately unfavorable. Whereas, 0 – 3% (level to nearly level) are the areas that are rated highly suitable for crop production. Most of the areas in the watershed that are rated as highly suitable for corn and garlic production are mostly located in the central to western part.

The topographic suitability map (Figure 13) shows that most lowland and central areas—notably in Batac and western Paoay—are highly suitable for both crops. The eastern uplands, however, are unsuitable for garlic and marginally suitable for corn due to steep slopes and erosion risks.

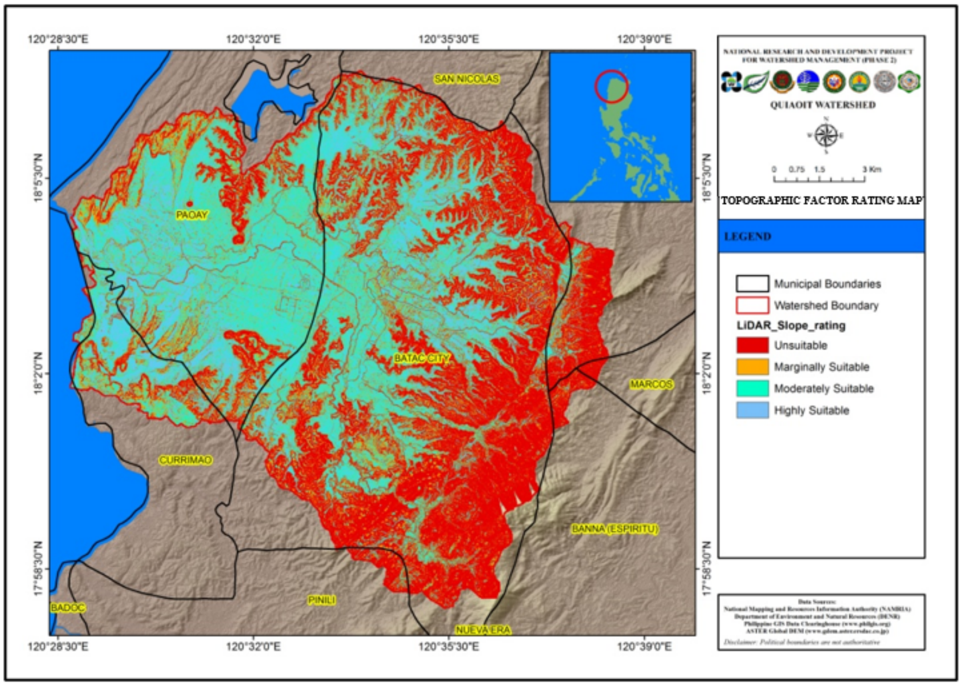

Figure 13. Topographic factor rating map in the QRW.

Water Availability Factor

Water is indispensable in crop production. The availability of irrigation water dictates the kind of crops to be planted. Farmers within the QRW usually apply 381.67 mm of irrigation water to corn, while 386.36 mm of irrigation water was applied to garlic throughout the entire production period.

The specific capacity of the aquifer to produce groundwater affects the availability of irrigation water and the suitability of the area for tubewell installation. The specific capacity of the aquifer ranges from 314.42 – 2667.02 m^3/m-day. Based on the criteria, this was classified as marginally suitable to highly suitable for crop production (Figure 14). Most of the areas in the watershed are classified as marginally to moderately suitable for tubewell installation. This could be validated by the numerous existing STWs installed within the watershed. The diameter of STWs installed in the area, which usually ranges from 1.5' – 2'', further proved that the area is only marginally to moderately suitable for STW installation. The volume of available groundwater that can be extracted within the QRW is not adequate, which is why smaller diameter pipes were installed for the sustainability of these pipes.

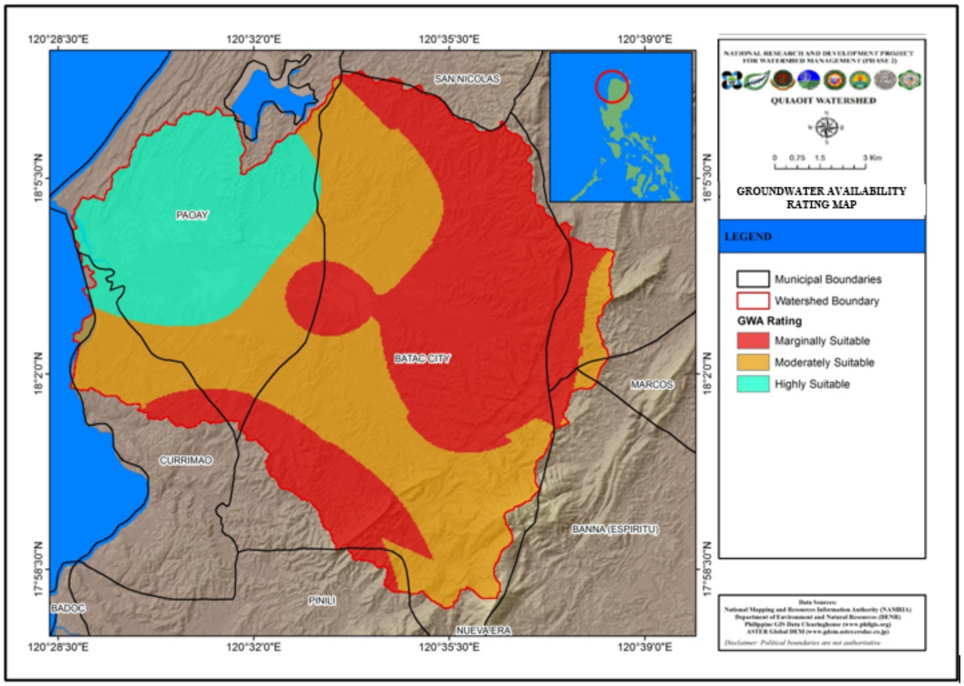

Figure 14. Groundwater availability rating map in the QRW.

Composite Suitability and Distribution of Suitable Areas for Corn and Garlic Production

The weighted overlay analysis, integrating all four factor maps (climate, soil, topography, and water), produced composite land suitability maps for corn and garlic (Figures 15 and 16). These maps generated maps present the spatial distribution of suitability by municipality.

- Paoay contains most of the Highly Suitable areas for corn, particularly in its western and central portions, where soil fertility and groundwater are favorable. These zones also sustain the chichacorn industry.
- Batac holds extensive Moderately Suitable areas for both corn and garlic, attributed to deep clay loam soils but constrained by moderate slopes (5–12%).
- Currimao exhibits smaller agricultural areas, mostly Moderately – Marginally Suitable, limited by shallower soils and salinity intrusion near the coast.

Based on the generated garlic suitability map, most areas within the Quiaoit River Watershed (QRW) were classified as moderately suitable, with no areas identified as highly suitable for garlic production. This pattern is consistent with historical garlic yield data from 2010 to 2016 across municipalities in Ilocos Norte. During this period, Batac, Currimao, and Paoay recorded average yields of 2.71, 2.72, and 2.90 t/ha, respectively, ranking 13th, 12th, and 8th in provincial garlic production. These relatively modest rankings support the model's indication that growing conditions in the QRW are generally adequate but not optimal for high-yield garlic cultivation.

In general, higher garlic yields were observed in the northern municipalities compared to those in the southern part of the province, a trend that may be largely influenced by more favorable climatic conditions, particularly temperature and rainfall patterns, in the north. Overall, the suitability assessment aligns well with observed production trends, lending confidence to the results of the analysis. A detailed breakdown of the suitability classes for both corn and garlic within the QRW is presented in Table 4.

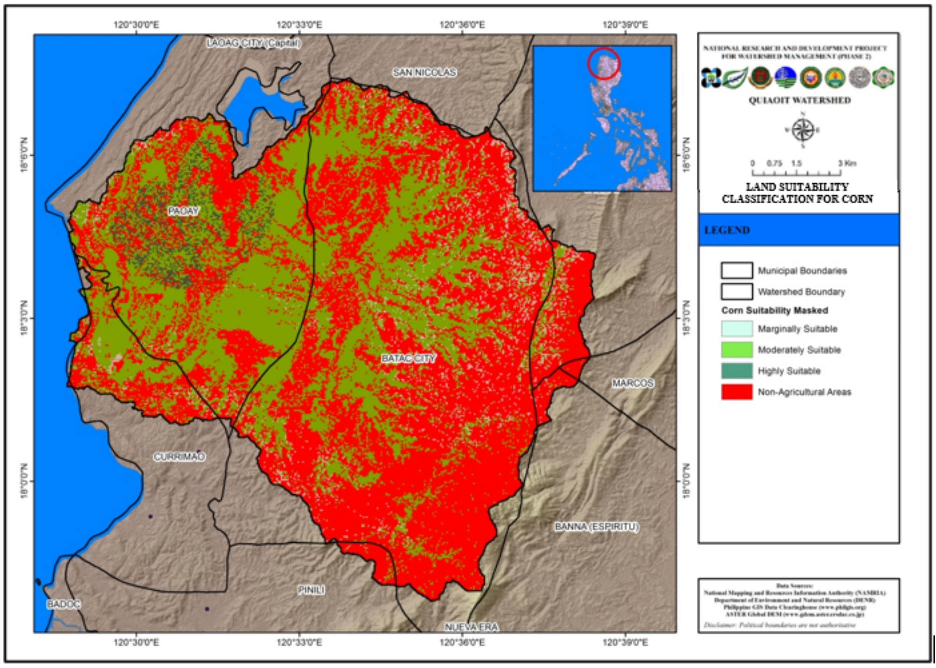

Figure 15. Suitability map for corn production in the QRW.

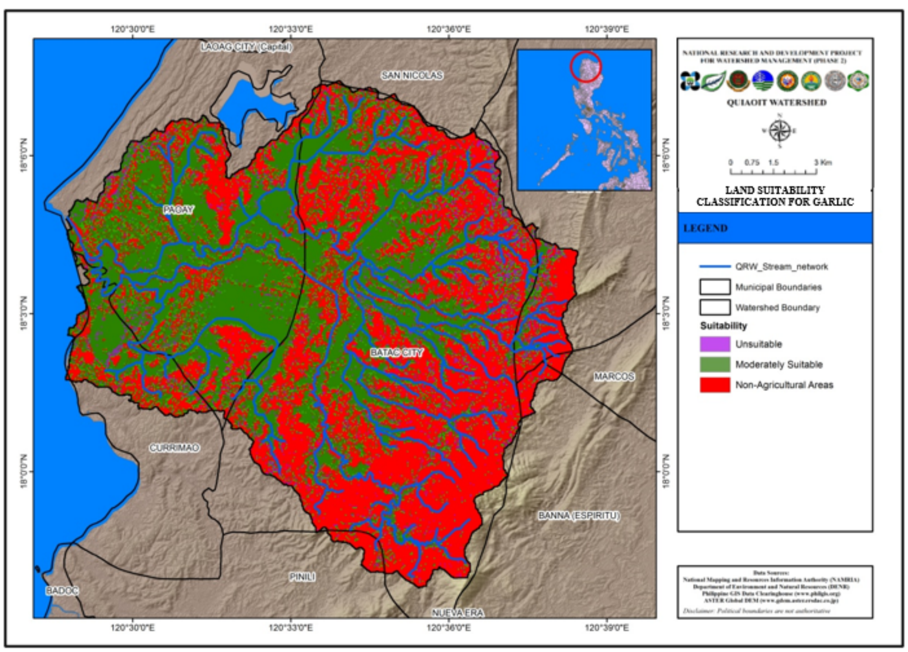

Figure 16. Suitability map for garlic production in the QRW

Table 4. Area covered per suitability classification of garlic in the QRW.

Suitability Class	Crops	
	Corn	Garlic
Unsuitable, ha.	0.00	0.00
Marginally suitable, ha.	793.25	441.00
Moderately suitable, ha.	7640.00	8420.25
Highly suitable, ha.	419.50	0.00
Total, ha.	8852.75	8861.25

Validation and Analysis

Field validation was conducted to evaluate the reliability of the GIS-based land suitability maps by linking model outputs with observable field conditions in the Quiaoit River Watershed. Validation was primarily based on crop occurrence and visual assessment of key physical suitability factors, rather than crop yield data. A total of 50 validation points were strategically distributed across the watershed to represent the full range of suitability classes for corn and garlic.

At each validation point, the presence or absence of the target crop served as the initial basis for validation. Areas where corn or garlic was observed were considered suitable, recognizing that crop occurrence reflects not only favorable biophysical conditions but also farmers' crop preferences, management decisions, and available financial resources. In some cases, suitable land may not be planted with the target crop due to limited capital, market considerations, or household priorities, rather than physical constraints alone.

For locations where the crop was absent, suitability was evaluated through visual inspection of physical factors aligned with the model criteria, including physical soil properties, topography, land use/land cover, and water availability. Following this initial classification, a second level of refinement was applied. Areas where corn and garlic occurred, which were initially identified as suitable, were further reclassified into highly suitable and moderately suitable based on the physical factors considered in the criteria.

Using this two-stage validation approach, the model achieved an overall accuracy of approximately 90.0% for corn (Table 5a) and 84.00% for garlic (Table 5b), indicating strong agreement between predicted suitability and observed crop occurrence and field-based physical conditions. Minor discrepancies were largely attributable to socio-economic factors or localized management interventions that influenced cropping patterns without fully reflecting inherent land capability.

Table 5a. Confusion (Error) Matrix of Land Suitability Classification for Corn on 50 Validation Points

Predicted	Observed				Total
	Highly Suitable	Moderately Suitable	Marginally Suitable	Not Suitable	
Highly Suitable	13	1	0	0	14
Moderately Suitable	0	24	1	0	25

Predicted	Observed				Total
	Highly Suitable	Moderately Suitable	Marginally Suitable	Not Suitable	
Marginally Suitable	1	2	8	0	11
Not Suitable	0	0	0	0	0
Total	14	27	9	0	50

- Overall Accuracy: 45 / 50 = 90.0%

Table 5b. Confusion (Error) Matrix of Land Suitability Classification for Garlic on 50 Validation Points

Predicted	Observed			Total
	Moderately Suitable	Marginally Suitable	Not Suitable	
Moderately Suitable	16	3	0	19
Marginally Suitable	5	26	0	31
Not Suitable	0	0	0	0
Total	21	29	0	50

Overall Accuracy: 42 / 50 = 84.0% (84.0%)

Overall, the validation confirms that the GIS–AHP framework effectively captures the dominant physical and chemical factors governing land suitability for corn and garlic. By explicitly accounting for both biophysical conditions and the socio-economic context of farming decisions, the generated suitability maps are shown to be reliable and practical tools for crop zoning, land-use planning, and climate-responsive agricultural development.

Discussion

Climate Resilience

The climate of the Quiaoit River Watershed naturally supports corn production, which helps explain why corn has remained a dependable crop for farmers in the area over many years. Its ability to tolerate moderate temperature fluctuations and make good use of seasonal rainfall allows it to perform well under the watershed's distinct wet and dry seasons. This resilience is especially important in places like Paoay and Batac, where corn farming is closely tied to household income and local enterprises such as the chichacorn industry.

Garlic, however, tells a more delicate story. While it can still grow under current climatic conditions, it is far more sensitive to heat, particularly during the stages when bulbs are forming. Even slight increases in temperature or irregular rainfall can affect bulb size and quality, making yields less predictable. These vulnerabilities reflect broader climate trends in northern Luzon, where warmer conditions are increasingly shaping what crops can thrive and how they must be managed.

Building climate resilience for garlic, therefore, requires farmers to adapt rather than rely solely on traditional practices. Simple but effective measures—such as adjusting planting schedules, using mulches to cool the soil, or selecting varieties better suited to warmer conditions—can make a meaningful difference. When supported by timely climate information and extension services, these adjustments can help farmers reduce risks and sustain garlic production despite a changing climate.

Soil Constraints and Management Opportunities

Soil fertility remains the primary limiting factor across the watershed. The widespread low organic matter (<2%) and marginal phosphorus levels indicate nutrient depletion caused by intensive cultivation and limited use of organic amendments. This mirrors the trend observed in other Ilocos agricultural watersheds, where conventional tillage and residue removal contribute to soil degradation (Amongo et al., 2023).

Improving soil organic matter through integrated nutrient management — combining compost, green manure, and balanced NPK fertilization — can restore soil productivity and enhance water retention. Such practices have proven effective in the Ilocos region for improving garlic bulb yield and corn grain quality (Bucao et al., 2023). Likewise, pH management through liming in acidic patches can optimize phosphorus availability and microbial activity.

For the moderately sloping uplands, soil conservation measures such as contour farming, strip cropping, and grass hedgerows should be implemented to minimize erosion, enhance infiltration, and sustain soil depth for crop roots.

Influence of Slope and Topography

Topography exerts a strong influence on both water movement and soil formation. The results confirm that suitability declines markedly at slopes exceeding 15–18%, primarily due to erosion risk and tillage constraints. These slope thresholds are consistent with BSWM's national standards for sustainable land management (BSWM, 2022).

While corn exhibits better adaptability on gently sloping terrain (3–12%), garlic is more sensitive to drainage and root aeration issues. Thus, crop zoning that allocates corn to slightly rolling uplands and garlic to level or near-level lands is recommended. In steep zones, agroforestry or perennial crops may serve as alternative land uses to reduce degradation.

Water Management

Water availability remains one of the watershed's most valuable assets for agriculture. Groundwater resources in the QRW have long supported dry-season farming, allowing corn and garlic to be cultivated even when rainfall is scarce. For many farmers, shallow tube wells are not just infrastructure but a lifeline that enables them to maintain production beyond the rainy season.

At the same time, the study highlights an important reality: groundwater resources are not unlimited. In many parts of the watershed, aquifer capacity is only marginal to moderate, which explains the widespread use of small-diameter wells designed to avoid excessive extraction. This local practice reflects an unspoken understanding among farmers—that overuse today could mean scarcity tomorrow.

As dry seasons become longer and water demand increases, efficient water use becomes increasingly critical. Techniques such as drip irrigation, mulching, and rainwater harvesting offer practical ways to stretch limited water supplies while still meeting crop needs. Beyond the farm level, coordinated groundwater monitoring and recharge efforts are essential to ensure that irrigation remains viable for future generations.

Taken together, careful water management is not just about sustaining crops in the present—it is about protecting the watershed's capacity to support agriculture in the long term. By combining efficient irrigation practices with responsible groundwater use, the QRW can continue to support productive and resilient farming systems under growing climate pressures.

Overall Suitability Patterns and Implications

The GIS-based land suitability analysis demonstrated that the Quiaoit River Watershed (QRW) possesses predominantly moderate to high suitability for corn and moderate suitability for garlic. These findings are consistent with earlier assessments (Bucao et al., 2023) but with enhanced spatial precision due to updated LiDAR-derived terrain data, AHP weighting, and refined soil fertility mapping.

The high proportion of S1–S2 areas for corn (over 90%) underscores the watershed's natural advantage for cereals, particularly in Paoay and Batac, where deep, well-drained clay loam soils and abundant groundwater resources prevail. Corn thrives in the area's Type I climate, where dry-season cultivation coincides with moderate temperatures and adequate irrigation potential. These agroecological conditions underpin Paoay's local chichacorn industry, a community-based enterprise that transforms glutinous corn into a high-value product.

In contrast, garlic showed fewer highly suitable areas, largely due to low organic matter and elevated temperatures during bulb development. This aligns with findings by Salvacion et al. (2023), who projected a reduction in garlic suitability in northern Luzon under warmer climate scenarios. Nevertheless, moderately suitable (S2) zones still dominate central and mid-elevation areas, suggesting potential for sustained production through improved soil management and irrigation interventions.

Integration with Agricultural Policy and Planning

The suitability maps generated in this study complement the Department of Agriculture's (DA, 2023) updated National Color-Coded Agricultural Guide (NCCAG), which aims to align land-use decisions with crop-envir
compatibility. By delineating high 64
moderately suitable zones, this asse
provides evidence-based guidance for:

- Local Government Units (LGUs) to integrate crop zoning into their Comprehensive Land Use Plans (CLUPs);
- Farmers' cooperatives to optimize crop rotation and diversify production systems; and
- Development agencies to prioritize investments in soil fertility restoration and irrigation infrastructure.

This geospatial framework also supports the Philippine Development Plan 2023–2028, which emphasizes climate-smart agriculture and sustainable watershed management. The QRW, being both agriculturally productive and environmentally sensitive, offers an ideal model for integrating land suitability mapping into regional agricultural planning.

Strategic Implications

Given the predominance of S2-class lands, management should focus on upgrading marginally suitable zones through targeted interventions:

- Application of organic fertilizers and biochar to boost soil fertility.
- Rehabilitation of communal irrigation systems for stable dry-season garlic production.
- Capacity building for farmers on climate-smart practices and soil health management.

By integrating these interventions, the QRW can serve as a demonstration site for sustainable, climate-resilient agriculture in Region I.

Overall, this study highlights how combining GIS, AHP, and soil-climate analysis provides a robust framework for assessing land suitability. The results reaffirm that the QRW's natural resources can sustain high-value crops when supported by appropriate management technologies. Strengthening local adoption of land suitability maps ensures that agricultural expansion remains both economically viable and environmentally sound, fulfilling national goals for sustainable watershed-based development.

Conclusion

This study used GIS and the Analytical Hierarchy Process (AHP) to take a closer look at how the Quiaoit River Watershed (QRW) supports corn (Zea mays L.) and garlic (Allium sativum L.) production. By combining information on soil, climate, topography, and water resources, areas that are best suited for these crops were mapped out. Most of the watershed came out as moderately to highly suitable for corn (about 91%) and moderately suitable for garlic (around 95%).

Corn thrives especially well in the lowland and central parts of Paoay and Batac, where deep, well-drained clay loam soils and reliable groundwater make farming more productive. These areas also support the local chichacorn industry, showing a clear link between the land's potential and local livelihoods. Garlic, while fairly suitable in much of the watershed, faces some challenges—mainly low soil organic matter and higher temperatures during the crucial bulb development stage.

While the study highlights GIS–AHP as a powerful tool for assessing crop potential and guiding land-use planning, it's important to remember its limitations. The maps reflect the data available at the time and don't yet include ongoing monitoring or updates, so seasonal changes, data uncertainties, and climate variations could affect the results. Building in regular monitoring and feedback would make future assessments even more reliable.

Overall, the findings give a clear picture of where corn and garlic can thrive, helping guide sustainable farming, crop zoning, and climate-smart agricultural planning in Ilocos Norte. At the same time, they remind us that land suitability is not static—keeping maps and data up to date will be key to long-term success.

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References

Amongo, R. M., Saludes, R., Gallegos, R. K., Relativo, P. L., Duminding, R. S., Pantano, A. D., Cunan, J. J. P., & Lalap-Borja, G. N. (2023). A GIS-based land suitability model for agricultural tractors in CALABARZON Region, Philippines. *Scientific Reports, 13*, Article 18272. https://doi.org/10.1038/s41598-023-45071-w Nature+1

Bilas, G. (2022). Land suitability analysis as a tool for evaluating soil-based agricultural potential under current and future scenarios. *Land, 11*(12), 2200. https://doi.org/10.3390/land11122200 MDPI

Bucao, D. S., Utrera, R. T., Galacgac, E. S., & Sagsagat, F. C. (2023). Land suitability assessment for garlic in Region I. *Science and Technology Journal, 9*(1), 20–35.

Consolacion, J., Marapao, G., Uy, W., Leopardas, V., Parungao, L., & Cabanilla, H. (2022). Suitability mapping of key crop commodities in Misamis Occidental, Philippines. *MSU Journal of Environment and Aquatic Resources, 6*, 71–85. https://doi.org/10.48031/MSUNJEAR.2022.06.05 Academia

Department of Agriculture (DA). (2023). *National Color-Coded Agricultural Guide (NCCAG) Map – 2023 Update.* Quezon City, Philippines.

Food and Agriculture Organization (FAO). (2020). *Guidelines for land evaluation for sustainable agriculture* (Soils Bulletin 32). Rome: FAO.

Malczewski, J., & Rinner, C. (2022). *Multicriteria decision analysis in geographic information science* (2nd ed.). Springer.

Nurmiaty, N., & Baja, S. (2022). GIS-based multi-criteria assessment of land suitability for maize and horticultural crops in Maros Region, South Sulawesi, Indonesia. *Open Journal of Soil Science, 12*(1), 87–101.

Salvacion, A. R. (2017). Mapping spatio-temporal changes in climatic suitability of corn in the Philippines under future climate condition. *Quaestiones Geographicae, 36*(1), 105–120. https://doi.org/10.1515/quageo-2017-0008 ResearchGate+1

Saaty, T. L. (1980). *The analytic hierarchy process: Planning, priority setting, resource allocation.* McGraw-Hill.